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original article

Four weeks of blood flow restricted training increases time to exhaustion at severe intensity cycling exercise

Quatro semanas de treinamento com restrição de fluxo sanguineo aumenta o tempo de exaustão em exercício severo no ciclismo

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Abstract – The present study aimed to verify the effects of 4 weeks of low-intensity blood flow restricted (BFR) training on time to exhaustion (Tlim) at severe-intensity exercise. Thirteen physically active subjects (23 ± 3.4 years; 70.6 ± 7.8 kg; 170.9 ± 10 cm) were assigned to one of two groups: low-intensity interval training with (BFR, n=9) or without (CON, n=4) blood flow restricted. The interval training sessions consisted of 2 sets of 5-8 × 2-min intervals at 30% of peak power output (P_{peak}) obtained during incremental exercise for LOW and BFR, separated by 1min of rest. For BFR a cuff was inflated (140-200mmHg) during the exercise bouts and deflated during rest intervals. The pressure was increased 20mmHg after three completed sessions, thus, in the last week the pressure applied was 200mmHg. Before and after 4 weeks intervention period, all subjects completed an incremental exercise until exhaustion and one-step transition to a severe-intensity work rate (110%P_{peak}). The results revealed that BFR (Pre: 227 ± 44s vs. Post: 338 ± 76s), but not CON (Pre: 236 ± 24s vs. Post: 212 ± 26s), increase significantly Tlim at 110%P_{peak}. It can be concluded that 4 weeks of BFR training, but not CON, increased the exercise tolerance at severe intensity domain. Therefore, the increased metabolic and physiologic strains induced by BFR, not the exercise intensity per se (30%P_{peak}), seem to have been responsible to trigger the adaptive responses linked to longer Tlim after BFR training.

Key words: Blood flow restriction; Cycling; Exercise tolerance; Training; Severe exercise.

Resumo – *Este estudo verificou o efeito de quatro semanas de treinamento de baixa intensidade com restrição do fluxo sanguíneo (RFS) no tempo de exaustão (Tlim) realizado em domínio severo. Treze sujeitos fisicamente ativos (23 ± 3,4 anos; 70.6 ± 7.8 kg; 170.9 ± 10 cm) foram divididos em dois grupos: treinamento intervalado com restrição de fluxo (RFS, n=9); e sem restrição (CON, n=4). O treino para ambos os grupos consistiu em 2 x 5-8 repetições de 2min a 30% da potência máxima (P_{peak}) obitida durante teste incremental, com intervalos de 1min entre as repetições. Para o RSF o esfigmomamometro foi inflado a uma pressão de 140-200mmHg durante o período de exercício e desinflado nos intervalos. A pressão foi aumentada em 20mmHg a cada três sessões, assim, na última semana a pressão era 200mmHg. Antes e depois das quatro semanas de intervenção, todos os sujeitos realizaram um teste incremental até exaustão voluntária e um teste de carga constante com intensidade de 110%P_{peak}. Os resultados mostraram que para o grupo BFR (Pre: 227±44s vs. Pos: 338±76s), mas não para o CON (Pre: 236±24s vs. Pos: 212±26s), o Tlim a 110%P_{peak} aumentou significativamente após treinamento. Podemos concluir que 4 semanas de treinamento com BFR aumentou a tolerância ao exercício realizado no domínio severo, sem aumento no grupo CON. Assim, o maior estresse metabólico e fisiológico gerado pela restrição do fluxo sanguíneo, e não a intensidade de exercício per se, parece ter sido responsável pelas respostas adaptativas relacionadas ao aumento do Tlim após o treinamento.*

Palavras-chave: *Ciclismo; Exercício severo; Restrição de fluxo sanguíneo; Treinamento; Tolerância ao exercício.*

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INTRODUCTION

Exercise intensity domains have been defined based upon their distinct metabolic profiles[1]. The moderate intensity domain consists of work rates at or below the lactate threshold (LT). The heavy domain includes work rates above LT, but at or below critical power (CP). The severe intensity domain encompasses work rates above CP in which maximal oxygen uptake (VO_2 max) can be elicited. In fact, in the severe domain VO_2 continues to increase over time until VO_2max is attained[2,3]. Therefore, it is not possible for a subject to perform a constant work rate that provides a VO_2 equivalent to a particular percentage of the VO_2 max. In addition, within the severe domain, termination of exercise is believed to coincide with the depletion of the finite anaerobic reserves (attainment of a critical concentration of one or more substrates), and an accumulation of a range of metabolic by-products (hydrogen ions, inorganic phosphates, or AMP), which have been linked to muscle fatigue[4]. Therefore, adaptation occurring with exercise training may implicate in reduction of intracellular disturbance and anaerobic substrates utilization during exhaustive exercise, prolonging maximal exercise duration (Tlim)[5]. However, few studies have analyzed the effects of exercise training on Tlim in the severe domain during cycling.

Although it may appear intuitive that high-intensity training (HIT) would be a better intervention than endurance training (ET) to improve Tlim at severe-intensity exercise, to date, only two studies have directly supported this premise[6,7]. While Bailey et al.[6] showed that six sessions of HIT improved (+53%) exercise tolerance during severe-intensity exercise, with a non-significant increase (+13%) for ET, Daussin et al.[7] showed a higher improvement after HIT (+129%) compared with ET (+64%). In both studies[6,7] Tlim improvement was associated with faster O_2 adjustments. Furthermore, Daussin et al.[7] showed that capillary density improves with ET, whereas capillary density, cardiac output and mitochondrial function were enhanced by HIT, suggesting that other factors beyond capillary density could be related to greater lengthening of Tlim after an experimental intervention such as exercise training.

Regardless of the training mode (HIT or ET), it has been recommended that exercise training aiming at improvements of cardiovascular fitness/endurance in healthy adults should be conducte at intensities above 50% VO_2 max[8]. On the other hand, recent studies using low intensities exercise (<50%VO_2 max) associated with a blood flow restriction (BFR) were able to improve VO_2 max[9,10] and exercise tolerance[10]. However, the effectiveness of a low-intensity BFR training in providing improvements on Tlim during severe-intensity exercise is still unknown. Increased muscle glycogen content[11,12]; increased stroke volume[9]; increased microvascular filtration capacity[13,14]; greater number of capillaries per fibre, higher percentage of type-I fibres and a lower percentage of IIB fibres[15]; and higher citrate synthase activity[15,16] have been found as consequences of different BFR or ischemic training regimes. As Tlim at severe-intensity exercise seems to be limited

by the depletion of the finite anaerobic reserves and to the attainment of a critical concentration of one or more substrates or metabolites[4], some of the BFR training-induced adaptive changes mentioned above linked to faster VO_2 kinetics (sparing anaerobic substrates) and lower intracellular disturbance (disposal of metabolic by-products), could increase exercise tolerance after low-intensity BFR training.

Thus, the purpose of the present study was to investigate the effects of low-intensity cycling training combined with BFR on Tlim at severe-intensity exercise in active subjects. We hypothesized that four weeks of BFR training would result in longer Tlim because some adaptations[10,13,15] generated by the BFR training may lead to reduction of intracellular disturbance and anaerobic substrates utilization during exhaustive severe exercise.

METHODOLOGICAL PROCEDURES

Participants

Thirteen young adults volunteered and gave written informed consent to participate in the study. Following the completion of initial incremental test (see below), the subjects were assigned to either low-intensity interval training with (BFR, n = 9, seven males and two females, mean ± standard-deviation body mass 69 ± 9 kg, age 22±5 years, height 174 ± 8 cm) or without (CON, n = 4, three males and one female, mean ± standard-deviation body mass 77 ± 11 kg, age 23 ± 2 years, height 168 ± 8 cm) blood flow restriction. Characteristics of the subjects are presented in table 1. All subjects were healthy with no known musculoskeletal or cardiorespiratory disease, and none were taking medications known that affect the cardiorespiratory system. Subjects were all recreationally active but not currently involved in a training program and were instructed to continue normal daily activities and to refrain from beginning any other training until the completion of the study. Participants were also instructed to maintain their normal diets over the course of the study. The study was approved by the local university ethics committee (protocol number 140/2011).

Experimental design

All subjects (OCC and CON group) performed two exercise protocols before (PRE) and after (POST) 4 weeks of training: 1) an incremental cycling exercise until exhaustion; and 2) a constant-load severe cycling exercise at a work rate (WR) corresponding to 110% of the P_{peak} determined PRE training. They were randomly divided into two training groups after the pre-tests. All subjects were requested to avoid performance on any moderate to intense exercise in the day prior to start of the experiments. The tests were performed in different days and were conducted at the same time for each subject.

Incremental test

The incremental cycling test began at 1.0 $W.Kg^{-1}$ (Lode Excalibur Sport;

Lode Medical Technology, Groningen, Netherlands), followed by a gradual increase of 35 W (for men) or 25 W (for women) every 3 minutes until voluntary exhaustion. Peak power output (P_{peak}). P_{peak} (W) at last stage completed was determined as follow: (W) + [t (s)/step duration (s) x step increment (W)]; "t" was the time of the uncompleted stage.

Time to exhaustion

The subjects performed a constant work-rate severe cycling exercise at 110%P_{peak} until voluntary exhaustion. The exercise test began with a 5 minute warm-up at 30% of the P_{peak} followed by 5 minutes of rest, after which the subjects were instructed to perform the required intensity until they were unable to maintain the fixed intensity. The time was recorded until the subject could not maintain a cadence of >70 rpm despite of verbal encouragement. Time to exhaustion was performed at the same absolute workload during the post-training period (110%P_{peak} pre-training).

Training Protocols

For both groups (OCC and CON) the training program consisted of three exercise sessions per week on a stationary cycle ergometer for a total duration of 4 weeks. Each exercise session consisted of 2 sets of 5 repetitions in the first week. After completing three sessions, one repetition/set was added per week; therefore, in the last week each session consisted of 2 sets of 8 repetitions. Each repetition lasted 2-min, interspersed by 1-min passive rest. The rest interval between sets was 5-min (3-min active recovery at 30%P_{peak} followed by 2-min passive rest). The training intensity was maintained at 30% of P_{peak} for LOW and OCC throughout training period. Every session was preceded by 5 minutes warm-up at 30% of P_{peak}. The OCC group used pressures cuff belts (18cm wide - aneroid auscultator Missouri®, Japan) at the proximal portion of both the legs during all training sessions. In the first week, cuff belts were inflated until 140mmHg during the repetitions (2-min), and deflated during the rest periods (1-min). The pressure was increased 20mmHg after three completed sessions, thus, in the last week the pressure applied was 200mmHg. The belt pressure was weekly increased to provide a continuously training stimulus because the belt air pressure during training was one of the exercise intensity variables and the subjects were adapted to the occlusion stimulus during the early phase of the training[9].

Statistical Analyses

Data are presented as mean ± standard deviation (SD). For each set of data, normal distribution (Shapiro-Wilk test) and homogeneity of variance were checked. Student t-test for paired samples was used to compare Tlim pre- to post-training values in BFR group, and for CON group, Wilcoxon test was used. Due to small sample size for CON group, nonparametric Mann-Whitney U tests were used for comparing Tlim between BFR and CON at pre- and at post-training condition. Statistical significance was declared when $P < 0.05$.

RESULTS

Exercise intensity at 110%P_{peak} pre-training corresponded to 260 ± 39 W and 243 ± 55 W for BFR and CON, respectively. No difference was found for the exercise intensity relative to 110%P_{peak} between BFR and CON. Tlim performed at 110%P_{peak} pre- and post-training for BFR and CON (Figure 1). No difference was found for Tlim pre-training between BFR and CON. The BFR group showed a significant increase in Tlim at post-training compared to pre-training ($p < 0.001$), while no differences in Tlim were observed for CON group after training. Significant difference also was found for Tlim post-training between BFR and CON ($p = 0.01$).

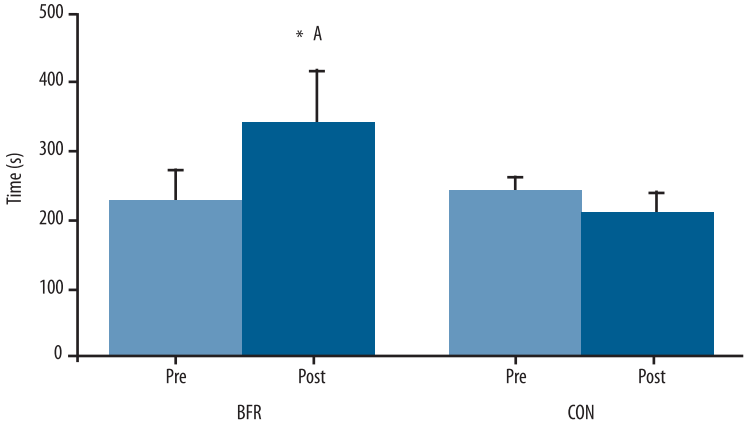

Figure 1. Mean ± SD of time to exhaustion performed at 110%P_{peak} before (pre) and after (post) training with (BFR) or without (CON) blood flow restricted. * significant different of pre-training ($P<0.05$); ^{A} significantly different from control post-training ($P<0.05$).

DISCUSSION

The aim of this study was to verify the influence of low-intensity aerobic interval training with blood flow restriction on Tlim performed at 110%P_{peak}. Our main finding was that 4 weeks of BFR training, but not CON, increased the exercise tolerance at severe intensity domain. Therefore, the increased metabolic and physiologic strains induced by BFR, not the exercise intensity per se (30%P_{peak}), seemed to have been responsible to trigger the adaptive responses linked to a lengthened Tlim after BFR cycling training.

The determinants of Tlim at severe intensity exercise are not fully understood, but seem be related to the depletion of the finite anaerobic reserves and an accumulation of a range of metabolic by-products[4]. Messonnier et al.[17] observed that Tlim at P_{peak} in sedentary individuals was positively correlated with the lactate exchange and removal abilities (i.e., a reduced intracellular metabolic by-products accumulation). In these individuals, lactate exchange ability was moderately correlated with capillary density and the number of capillaries per type I fiber area. Recently, Daussin et al.[7] showed that the greater lengthening of Tlim at severe-intensity exercise after HIT was not only associated with higher capillary density, but also to an enhanced cardiac output, mitochondrial function and faster VO_2

kinetics. Therefore, the adaptations provided by aerobic training seem to delay the depletion of the finite anaerobic reserves (by a faster and higher aerobic metabolism) and reduce the accumulation of a range of metabolic by-products (by a lower production and/or a higher removal ability).

Different BFR training regimes have also showed, similar to "traditional" aerobic training, central and peripheral adaptations[9,10,15]. Supine one-legged cycling training with 50 mmHg chamber pressure (reduced leg blood flow by 16%) for 4 weeks (4 sessions/week) resulted in an increase in muscle enzyme of oxidative metabolism and capillary density[15]. In addition, low-intensity continuous cycling and walking training with BFR have been able to enhance aerobic metabolism, reflected by an increase in stroke volume[9], VO_2 max[9,10] and exercise tolerance[10]. While Evans et al.[13] demonstrated an enhanced microvascular filtration capacity using resistance training with BFR in humans (as an index of capillarity), Suzuki et al.[18] showed evidence of greater capillarization in resistance-trained rats. Our BFR training design was able to provoke enhancements (53%) in Tlim at severe intensity exercise in similar magnitude to the others studies that used "traditional" high-intensity training[6,19], even using a very low intensity exercise (30%P_{peak}). Therefore, the increased Tlim observed after training in the present study suggest that, although not directly measured, the central and peripheral mechanisms underpinning a more extensive exhaustive exercise could have been also improved by our BFR training intervention.

Local hypoxia has been postulated to constitute a major signal for muscular adjustments to endurance exercise, given that there is a dramatic drop in muscle oxygen tension with the onset of exercise[20,21]. Furthermore, it has been shown that high-intensity interval training induces greater oxidative enzyme adaptations in type II fibers than continuous training[22], and that type IIb fibers manifest greater training-induced elevations in oxidative capacity as training intensity increases above VO_2 max[23]. Reducing blood flow to exercising limbs has also been shown to produce such adaptations. In the ischemic-trained leg, the skeletal muscle fiber type IIb proportion was lower and the type I proportion was higher in the trained than in the detrained state[15]. In addition, previous studies have reported greater BFR-induced muscle activation during low-intensity exercise[24,25], which was almost equal to that in the high-intensity exercise[25]. Since the availability of oxygen was severely reduced during our BFR protocol[26], a progressive recruitment of additional motor units (activate type II muscle fiber) might had taken place to compensate for the deficit in force development[24], probably inducing low-frequency adaptation in Type II fibers (e.g., oxidative capacity and higher fatigue resistance). All these fiber-type-specific adaptations would be expected to result in faster VO_2 kinetics, delayed anaerobic substrate depletion and enhanced tolerance to high-intensity exercise[27,28].

Even though time to exhaustion protocols have a higher coefficient of variation and lower ecologic validity[29] as a performance index than time trials protocols, the increase of Tlim observed in our study (53%)

indicates a training-induced adaptation, since the coefficient of variation of Tlim at intensities above VO_2 max appears to be between 5 and 10%[29,30]. Furthermore, the similar values pre- to post-training for CON indicate that low-intensity interval training (30%P_{peak}) on its own, without occlusion, was not sufficient to improve Tlim. From a practical point of view, considering that very low workloads can be performed during BFR cycling training, BFR method could be used for rehabilitation purposes in individuals aiming at maintenance of aerobic conditioning, or as a training routine for disability people (e.g., Paralympic athletes) or injured individuals who high mechanical loads could be contraindicated and/or unworkable.

FINAL COMMENTS

Four weeks of cycling low-intensity training with blood flow restriction were effective to increase the time to exhaustion at severe exercise (110%P_{peak}) in actives subjects. However, no significant changes on Tlim were observed for CON, who performed the training at the same relative intensity to the BFR group. Therefore, the increased metabolic and physiologic strains induced by blood flow restriction seem to have been responsible to trigger the adaptive responses linked to a longer Tlim after BFR training.

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